Observations of Be-W Interactions in PISCES-B

Work performed as part of US-EU bilateral Collaboration
On Plasma Material Interaction Experiments using
C/Be/W Materials at UCSD/PISCES-B Facility

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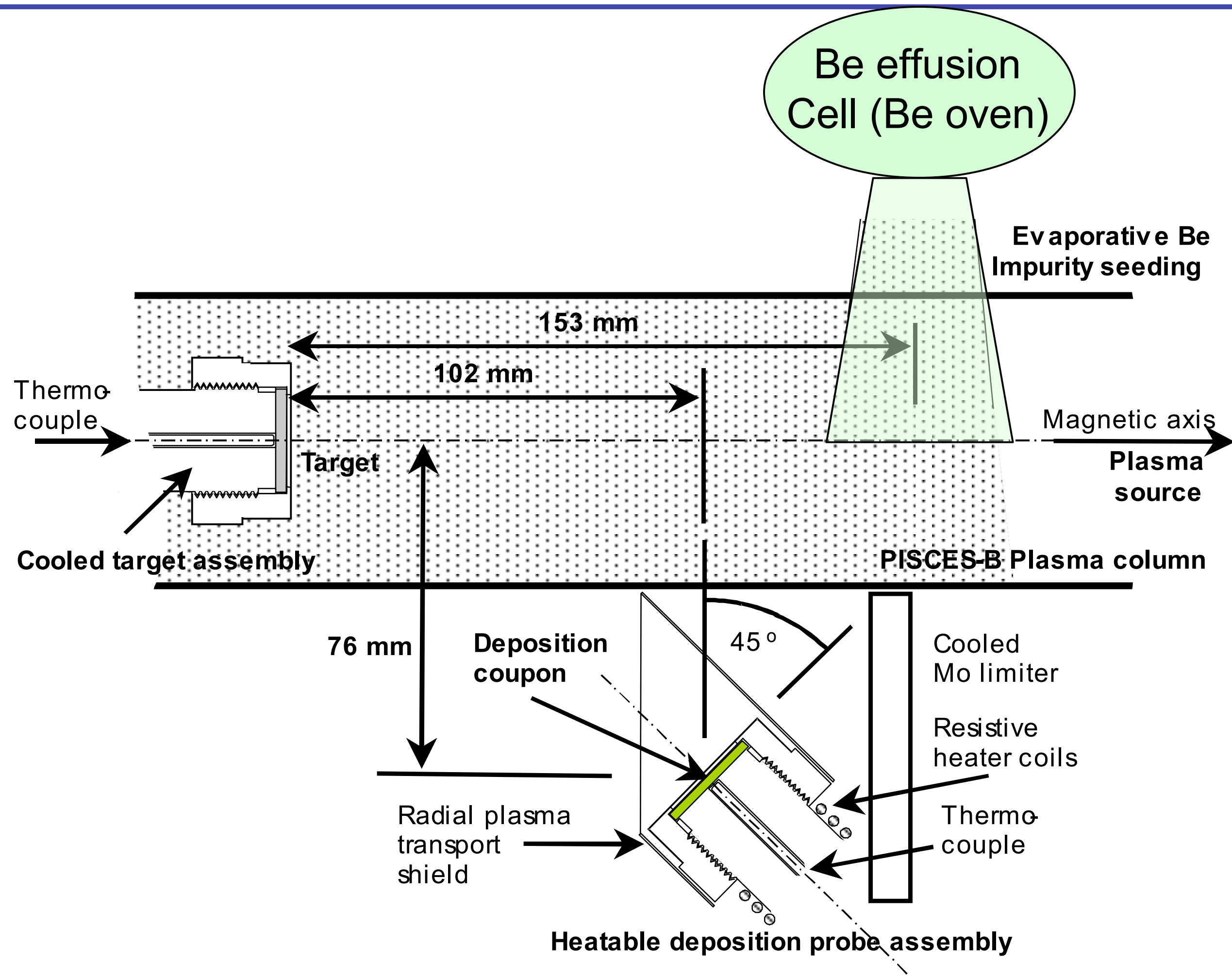
Be/C and C/W interactions have been studied in some detail. Be/W interactions at the plasma facing surface have not been studied.

- Be/C interactions are important for the ITER divertor plates, but Be/W interactions also need to be considered in the baffle regions

- JET is discussing a full Be first wall experiment where the divertor region could be all W, or a combination of C & W

- The FIRE design used a Be first wall and W divertor

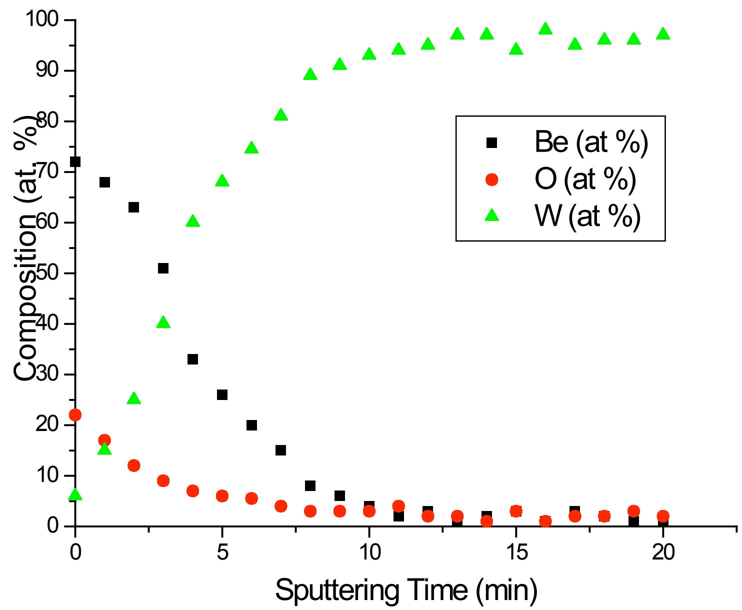
PISCES-B is equipped with an effusion cell to artificially seed Be impurities into D plasma



Be impurities from the ITER first wall will form Be surfaces on the tungsten baffle plates.

- Be layers have been observed on on W surfaces, as well as C
- Plasma exposure conditions
  - Be conc. ~0.1%
  - E_{ion} ~ 75 eV
  - T_W ~ 300°C
  - Ion flux ~ $1\times10^{22}\ m^{-2}s^{-1}$
  - Exposure time = 5000 sec.
- Estimated Be layer thickness on W is 10 nm
- Surface has 12 times as much Be as W

Surface composition of a W target exposed to a Be seeded deuterium plasma in PISCES-B



R. Doerner, Dec 6-8. 2004
DOE PFC meeting, Livermore CA.

Tungsten beryllides form in the target surface during PISCES-B exposures.

XPS data from PISCES-B
Be coated W sample

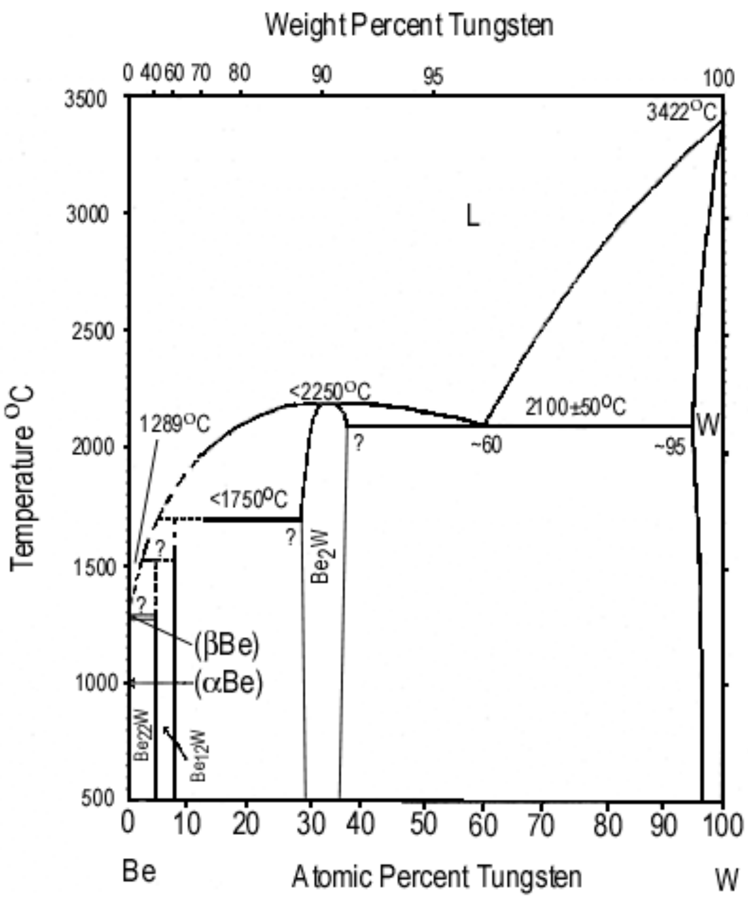
W 4f signal

38 34 30 26

Binding Energy (eV)

- Broadening (double peak formation) is observed after PISCES-B exposure in one of the W 4f doublet peaks
- During Be_2W alloy formation, measurements at IPP showed both W 4f doublet peaks broadened
- Specific phase of the Be-W alloy is not known

What will be the result of Be layers on plasma exposed W surfaces?

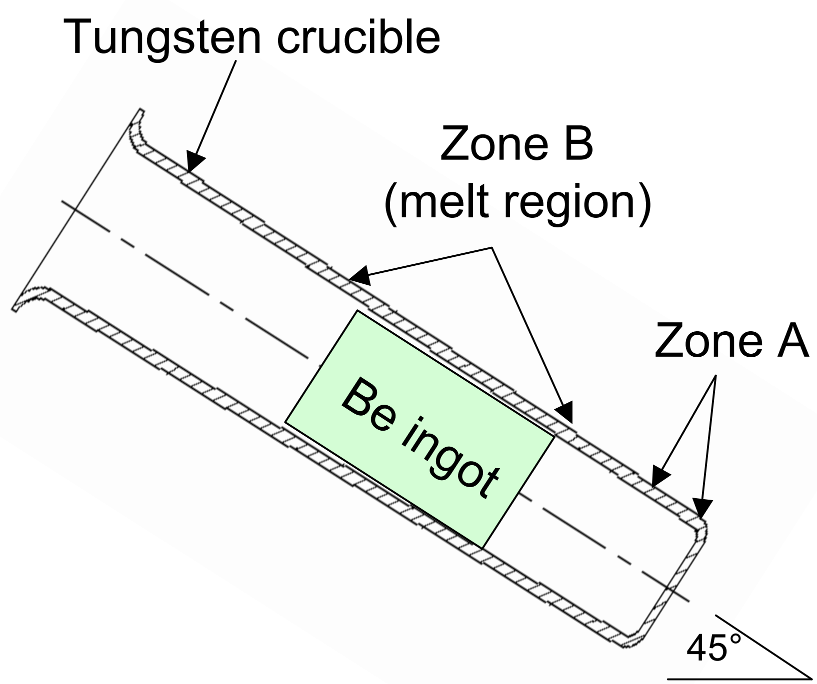


From H. Okamoto and L.E. Tanner, in "Phase Diagrams of Binary Tungsten Alloys", Ed. S.V. Naidu and P. Rao, Indian Institute of Metals, Calcutta, 1991.

- Be can alloy with W
- Resulting alloys ($Be_{22}W$ and $Be_{12}W$) have much lower melting temperatures (~1500°C)
- Be_2W alloy also has somewhat lower melting temperature (<2250°C)

PISCES-B Be oven used a W crucible. The W crucible melted.

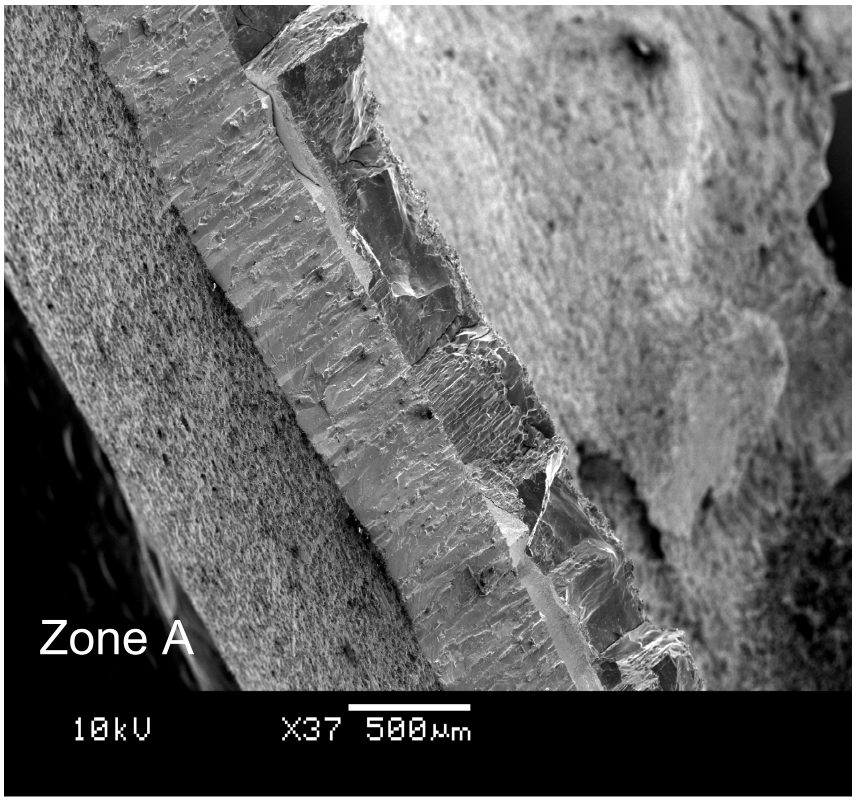
- Be oven temperature never exceeded 1550°C
- Typical operation and operating temperature when the oven failed was 1200°C
- Total lifetime of crucible was 100 hrs.
- Crucible wall thickness ~0.7mm
- $D_{Be\text{-}W}$ (1500°C) > 1 e-8 cm^2/s
- $D_{Be\text{-}BeO}$ (1500°C) ~ 1 e-9 cm^2/s
  [extrapolated from data in E.A. Gulbranse and K.F. Andrews, J. Electrochem. Soc. 97(1960)383.]



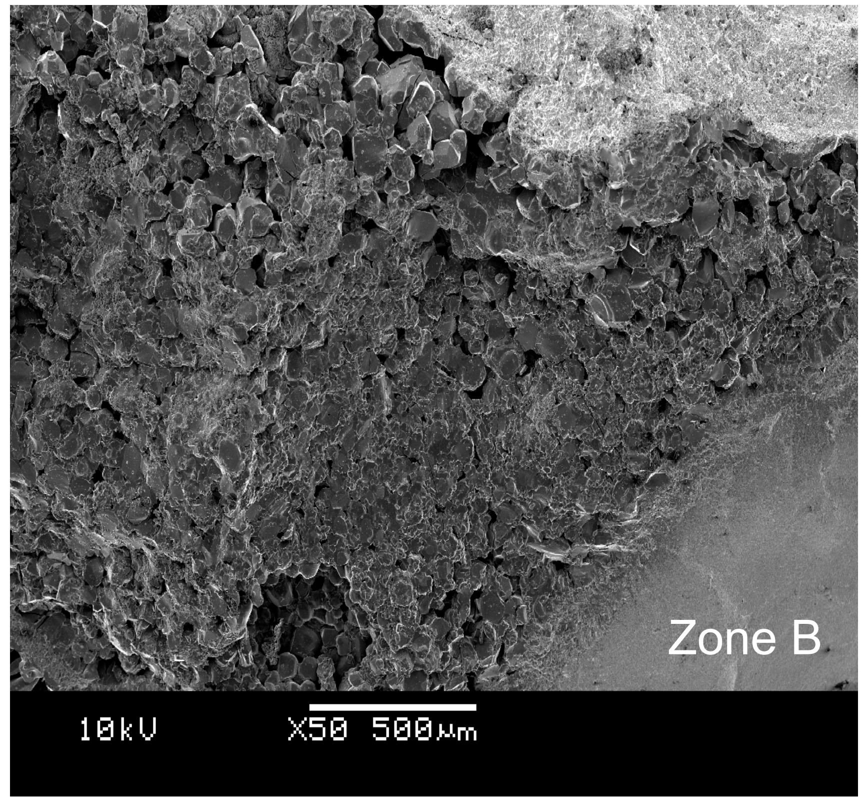
Two types of Be-W fragments were recovered from the crucible wreckage.

Intact W wall (97%W, 3%O)

Inner wall coating (4% W, 95% Be, 1%O) $Be_{22}W$?



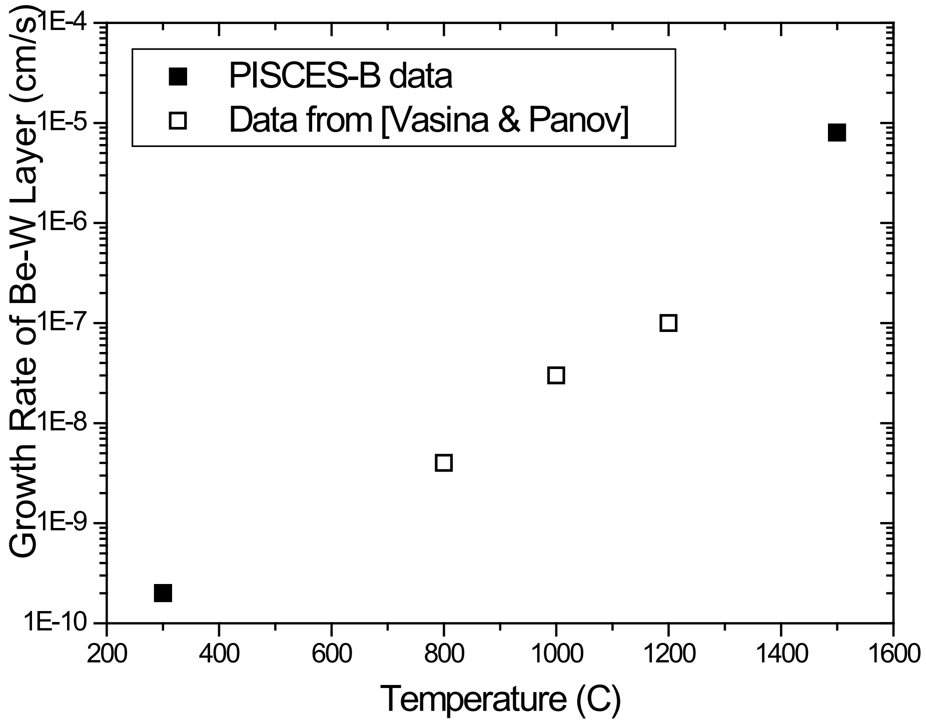
Crucible wall fragments from Be rich failure zone (9% W, 70% Be, 14% C, 7% O) $Be_{12}W$?



Formation of Be-W alloys ($Be_{12}W$, $Be_{22}W$, Be_2W) are well documented in the literature.

- E.A. Vasina and A.S. Panov, Russian Metallurgy, pg.119-121, 1974.
  - Reaction kinetics determine growth rate (for $Be_{12}W$)
    - @ 1000°C, R ~ 3 micron/hr
    - @ 1200°C, R ~ 30 micron/hr
- A. Wiltner and Ch. Linsmeier, PSI-16, 2004.
  - Observed alloy formation (Be_2W), but large Be surface evaporation appears to have limited growth rate at high temperature
- C.R. Watts, Int. J. of Powder Metallurgy, 3(1968)49.
  - $Be_{12}W$ begins to form at ~ 750°C
  - $Be_{22}W$ begins forming at ~ 980°C

$Be_{12}W$ growth rate agrees with PISCES-B data



Impact of Be-W alloy formation on ITER baffle plates varies widely depending on edge plasma assumptions.

- ITER IT assumes a Be flux limit of $10^{17}cm^{-2}s^{-1}$ (~0.1% Be impurity concentration), using 100% Be reaction
  - 0.5 micron of $Be_{12}W$ per 400 sec shot (or $3x10^{22}$ W atoms per shot)
    [no intermittent erosion of first wall]
- US-EU Collaboration assumes 1-10% Be impurity concentration
  - 5-50 microns $Be_{12}W$ per shot (10^{23}- 10^{24} W atoms per shot)
- PISCES-B growth rate at 1500°C (no Be flux limit)
  - 40 microns $Be_{12}W$ per shot (10^{24} W atoms per shot)

Large uncertainties exist in ability to predict ITER edge plasma conditions

A systematic investigation of Be-W interactions is urgently needed.

- Environment needed for characterization measurements
  - A Be rich environment is needed
  - Temperatures between 500°C – 2500°C are of interest

- Information needed
  - Formation and growth rates vs. temperature
  - Thermal properties of various alloys
    - Melting points
    - Thermal conductivity
    - Vapor pressure
  - Tritium retention
  - Grain boundary effects
  - Radiation damage

Coordinated work on "Be-W Issue" - UCSD and SNL (CA & NM)

Proposals for use of W and Be together in JET and ITER raises concerns about the formation of Be-W compounds on PFCs and potential damage.

UCSD and Sandia are collaborating on the experiments listed below.

- **UCSD:** When does a Be layer form on a W surface bombarded by a H plasma seeded with Be? D retention?
  PISCES *- formation rate ($T_{surface}$), Be ion flux*
- ***SNL CA:*** *How does Be penetrate into a W surface?*
  Effusion Cell *from UCSD - Be atom flux onto W at 800-1500 C*
- ***SNL NM:*** *Is there a likely damage mechanism from Be solute in W under repeated ELM-like heat loads?*
  PMTF *- "ELM" heat cycles on W rods with Be in surface*

We might consider expanding this as a possible IEA collaboration under the new Annex II Subtask on Solid surface PFCs (RE Nygren – US Leader)